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THE SHADING OF YOUNG CACAO

WE are publishing in this issue extracts from a post-graduate student's dissertation, submitted in part requirement for the Associateship of the College, on experiments on the shading of young cacao plants. The author had undertaken to present his results in a form suitable for publication but his papers were lost through enemy action. Rather than incur further delay and risk further losses of manuscript, it has seemed preferable simply to present extracts from his original paper together with a short discussion of their significance.

Everyone who has ever been concerned with establishing young cacao knows that much protection is necessary for the young plants during the dry seasons of the first two or three years of their growth. What has not been certainly known was exactly why shade is so beneficial. It is clear that shade has, or may have, three major effects, any or all of which might well be beneficial to a young plant during a dry season. Of these three effects, the first is the obvious direct one of reducing the insolation on the leaves of the young cacao plant; the second is the maintenance of a more humid and possibly cooler atmosphere around the plant; and the third is the protection of the soil, keeping the soil damper and possibly cooler, or at the very least reducing the rapidity of changes in the moisture content or temperature of the soil. Each of these major presumable "effects" of shade could obviously be further analysed, and many other possible minor effects can easily be presumed. But in the mind of all cacao planters these three are the major effects of the shade given to young cacao plants in the field. The probable relative importance of each of these has hitherto been a matter of conjecture, but it is thought that most planters have tended to assume that one or other of the two indirect effects, or at least the combined result of the two together, was at least as important as any direct beneficial result of reduced insolation; in fact it has even seemed possible that the direct effect of reducing insolation was really a disadvantage which had necessarily to be incurred in practical culture in order to obtain the vastly greater benefits of the protection of plant or soil from drought. In any event, nothing reliable has been known about the optimum amount of shade or insolation for the young cacao plant.

It is convenient and economical to shade the young cacao plant in the field by means of "temporary live shade". This may consist of crops like tannias, cassava and bananas planted among the young cacao plants; or it may consist of rings of rather tall bushes of species of Tephrosia or Crotalaria or similar plants; or again rows of readily rooting trees (such as Gliricidia) may be planted as poles a year in advance, alternating with the rows of sites in which the young cacao is to be planted out. Obviously it is impossible by such means to provide overhead shade without also providing some degree of "side-shade", which must tend to hold a more humid air around the young cacao plant and also to shade the ground. Nor can the planter by such means place his young cacao plant in exactly "half sunlight" or "three quarter sunlight". Yet if the desirable amount of shade were known and the ways in which it chiefly acts were understood, a planter could at least go a long way towards providing optimal conditions for his young plants. Thus, considerable effort and expenditure in achieving this result would be economically justified.

The investigations reported in this number were not intended to constitute any critical study of the matter, but are only of a preliminary and exploratory nature. Their main objective was to obtain data for assessing the conditions that would be necessary in a future, more critical study from which we might, for instance, be able to judge the size and number of plots necessary for reasonably reliable average results and the extent of the border effect of shade. But his results seem to be so striking as to merit immediate publication.

The artificial shade over the plots in this experiment was so high and the plots and the cacao plants both so small, that it was expected that the differences in the shade over the various plots would cause but very slight corresponding differences in the atmosphere around the cacao plants. All the plots, moreover, were so heavily mulched that it was also expected that the varying shade would have but little effect on the temperature of, or the evaporation from, the surface of the soil. Repeated measurements showed that these expectations were substantially fulfilled. The vastly better growth of plants under "three quarter shade" as compared with those in full sunlight, seems therefore to be ascribable to nothing else than the direct effect of shade. The observations thus seem to leave little room for doubt that the most important effect of the shade in young cacao may well be simply its direct one. But none the less it will be noted that the experiment does not prove that the less direct effects of shade are negligible, since these indirect effects were deliberately eliminated as far as possible on all plots in this experiment. Thus, for instance, it can still be argued that the shading of the soil would have been highly beneficial to the young plants in shade as compared to those in the open, if all plots had not been so heavily mulched. And it can also well be argued that the absence of side protection around each cacao plant would have been very disadvantageous if the whole area of land used in the experiment had not been well protected from wind by high hedges, surrounding the land at no great distance. But the fact remains that the plants in full sunlight made relatively little growth during the wet season and stood almost stationary all through the dry season, in spite of a very heavy mulching and good windbreak protection, while the plants in "three-quarter shade" were making growth that was very good indeed for such dry weather. And, as may be judged from the light-meter measurements, "three-quarter shade" meant an amount of light that seems surprisingly small for a growing plant, and probably much less than falls on the average young cacao plant even in a well managed new planting.

PETROL AS A GRAIN FUMIGANT

The following trials with petrol as a grain fumigant are reported by Mr. W. V. Harris of the Tanganyika Department of Agriculture and published in the *East African Journal*, Vol. VIII, No. 1:—

(*a*) To a seed bin, 2 cu. ft. capacity, filled with infested maize, 1 fluid oz. petrol was added. The lid did not fit very well so one thickness of brown paper was tied over. After 48 hours the bin was opened. Practically all the weevils were found alive, congregated at the bottom of the bin.

(*b*) To an airtight box of 4 cu. ft. capacity filled with infested maize, 4 fl. oz. petrol was added. After 48 hours, two live *Calandra* were found, several hundred were dead and did not recover after airing for 24 hours. Numerous *Tribolium* (flour beetles) were all dead.

(*c*) Similar box and treatment using beans (*Phaseolus vulgaris*) heavily infested with *Bruchus* (so-called "bean weevils"), to which mill sweepings containing a large variety of stored produce insects had been added as well. Result—all *Bruchus* and other insects dead except the larvae of the large black Cadelle beetle.

Petrol thus appears to have definite possibilities as a fumigant. Germination tests have shown no ill effect with maize or beans. Owing to its lightness, petrol vapour requires a much tighter container than does carbon bisulphide and that is going to be a practical difficulty. One pint of petrol to 25 cubic feet would be a fair quantity for a well-sealed container. This is a lot compared with the standard dose of 0.15 pint of carbon bisulphide for the same volume of container, but now that carbon bisulphide is unobtainable the objection loses its force.

THE EFFECT OF SHADE ON THE GROWTH RATE OF CACAO CUTTINGS

BY

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Aim of Work

The present investigation was carried out as a preliminary investigation to precede a longer term series of experiments on the effect of shade on growing cacao and, eventually, on yield. The main object has been to determine the necessary light intensity for optimum growth of cacao cuttings.

Experimental Lay-out

Land near the College was used for the experiment, measuring 130 ft. long by 60 ft. wide, the long side running approximately North and South. The nursery was supplied with poles 8 ft. high erected at 10 ft. intervals both along and across the field, thus marking off 13 × 6=78 plots, each plot being 10 ft. square. These poles were provided with cross supports at the top, also running in both directions, and this arrangement formed the support for the different shading units later supplied.

Up to September 6th, 1941, the nursery had been used for a variety of purposes, and immediately prior to the present experiment contained a mixture of bananas, maize, and thin ground vegetation. Variations in soil fertility were obvious, especially towards the south end of the field, where the maize crop became visibly poorer. These were roughly mapped by inspection and recorded.

The nursery was protected from the prevailing easterly winds by an effective windbreak on three sides, and to the west it was bounded by a plot of cacao with Gliricidia shade. Thus the very oblique rays of the sun of the early mornings and late afternoons were eliminated from the plots.

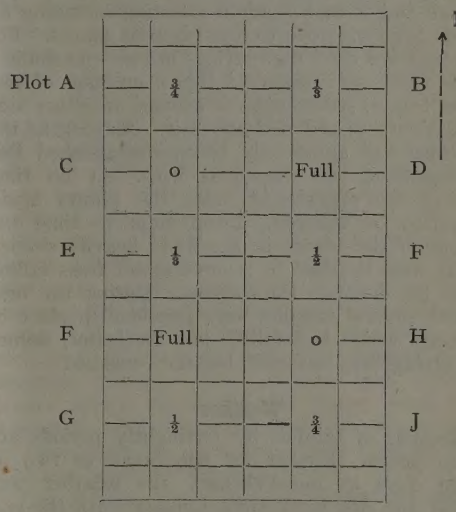
A randomised block experiment was laid down consisting of ten plots, with five shade treatments and two replications of each treatment. The plots were made as nearly square as possible in order to reduce the border effect, which in any case would be considerable. The treatments given were :

Full shade (*i.e.* complete canopy)
Three-quarter shade
Half shade
One-third shade
No shade

Each plot comprised six of the small areas into which the field was divided by the poles, and measured 30 ft. by 20 ft., the longer side lying in the direction East to West.

The design of the experiment is shown in the plan

Plan of Plots with Different Proportions of Shade



Method of Shading

To achieve the different shading intensities canopies of split bamboo poles were used, supported on the cross pieces 8 ft. from the ground. The bamboos were split longitudinally and the split halves used for the canopies. Full shading was obtained by fixing the bamboo slats as closely together as possible over the whole plot area and covering with palm leaves, resulting in a complete shading of the plot from direct sunlight, admitting only diffuse light from the sides. Three-quarter shade was obtained by removing every fourth bamboo slat from a completely covered area and re-spacing the remainder; half shading by removing every other bamboo slat and one-third shading by removing two slats in every three. The unshaded plots were completely open overhead. The bamboo slats were laid North-South, ensuring that during the daily cycle of the sun all the ground received shade at some time. Owing to the uneven nature of the bamboo poles employed, the shading was not everywhere exactly that required, but only a close approximation. But in any event, the exact fraction of such shading has little significance, since its effect must depend largely on the amount of light which reaches the plants from the sides of the plots; and this is merely a function of the height at which the shade is fixed and of the size of the unit plot; while the light even in the centre of each plot is affected in some small degree by the kinds of plot that adjoin it.

Material

The material used in the experiment consisted of cuttings of I.C.S. 1 cacao, planted at intervals approximately 4 ft. by 4 ft.; 28 cuttings in each plot. Each cutting received a dressing of potassium sulphate as it was planted (in October, 1941). After planting the whole area was very heavily mulched with Guatemala grass. The cuttings were obtained from the College propagators and were a random selection including all kinds from vigorous to less vigorous plants. For the first few days the cuttings in the "no-shade" plots were each protected by an erection of two palm leaves, stuck into the ground on either side of the cutting and tied above it. As soon as the cuttings had apparently become established this arrangement was dispensed with. At no time during the experiment were the plants again manured or watered. From time to time the leaves of the plants in the more heavily shaded areas were brushed to remove insect frass falling from the bamboo slats above. During the first month several supplies were provided in place of cuttings which had failed, but thereafter, failure of cuttings was recorded, but not remedied.

Weather

Records of rainfall by fortnightly periods are given below. Except for one break of two or three days in mid-February the weather was bright and dry from early January until the end of April. Even the substantial shower that fell at that one time in February only modified the general aridity for a very short while. By the general consent of local opinion it was as "severe" (which includes cloudless) a dry season as has occurred in the district for many years, though it ended punctually or even a little early.

Rainfall.

November	1 - 14		7.14
,,	15 - 28		4.39
,,	29 - 12	Dec.	2.58
December	13 - 26		0.44
,,	27 - 9	Jan.	0.20
January	10 - 23		0.43
,,	24 - 6	Feb.	0.00
February	7 - 20		1.47*
,,	21 - 6	March	0.00
March	7 - 20		0.32
,,	21 - 3	April	0.03
April	4 - 17		0.14
,,	18 - 1	May	2.39

* 0.87 on February 10th.

Measurement of Growth Rate

None of the methods available for measuring the growth rate of a plant growing in the ground is entirely satisfactory. The method adopted after much consideration was simply that of measuring the height of each cutting, from the ground to the growing point, at fortnightly intervals. While this method offers a general indication of the growth changes of each cutting, its many disadvantages must be borne in mind. Measurement of height does not take into account changes in thickness, in leaf area or leaf number, in root development or dry weight. But in the case of cacao cuttings up to one year old, until branching occurs to complicate measurements, changes in height do indicate fairly closely the changes in the general state of the cutting. The measurements, however, fail to convey fully the striking differences between the different groups of cuttings as they appeared on inspection.

Owing to its curious method of growth by means of periodic flushing, cacao offers another means of growth rate measurement. Periodically the growing point produces a number of young leaves, and the terminal bud elongates to produce a young green portion of the stem bearing young leaves, which are limp, coloured and pendulous, having none of the leathery texture of older leaves. These gradually harden and darken in colour and the stem produces bark. The state of flush of each cutting was recorded fortnightly along with the height measurements.

Measurement of Light Intensity

Although accurate quantitative measurements of average or total light intensity are not possible (or certainly not without very extensive and elaborate equipment) measurements were made from time to time with a small Avo Lightmeter of the photoelectric cell type. Numerous readings were taken at different places in each plot, the instrument being held at the height of the plants. Fair estimates in flecked shade are difficult to obtain, since the readings differ so widely according to whether the instrument lies in the sunny or shaded parts. But by taking into account the areas of shaded and unshaded ground approximately fair readings for each plot could be arrived at. The observations which are recorded in Table 2 were carried out between the hours of 10 a.m. and 3 p.m. in bright sunlight. Attempts were also made to obtain similar measurements during cloudy days and periods, but the light was found to vary too rapidly at such times to admit of comparable estimations.

Other Factors

(*a*) Temperature

Soil and air temperatures were recorded in the different plots at intervals during the course of the experiment. The soil temperature in Table 4 is that of the first four inches of soil. Readings were only taken between the hours of 10 a.m. and 2 p.m. and several readings were recorded each time, the mean then being entered up.

(*b*) Gross Soil Moisture Content

Samples of the soil from the different plots were collected at intervals, usually two samples being taken from each plot. Round cigarette tins were used as convenient sampling containers. These were weighed first, then filled with soil, reweighed

and placed in a drying oven for 48 hours. They were then reweighed and the loss in weight due to loss of soil moisture calculated. The percentage soil moisture content could thus be determined.

(*c*) MORTALITIES

A record was kept of the number of trees which failed in each plot throughout the investigation.

Results and Conclusions

GROWTH RATE

Measuring the heights of 280 trees fortnightly produced a mass of data : for each of the ten plots the heights of the trees were summed and these aggregate heights were the figures dealt with. But since such a figure includes the heights of all the trees, including the guard row trees on each side, a second aggregate figure was taken : that of the centre ten trees of each plot, these being the trees which received even shading. Comparison of the two aggregate heights gives some indication of the border effect between plots. Table 1 and Fig. 1 show the percentage increase in aggregate height under the 5 different shade treatments :—

(*a*) over the total period,
(*b*) during the wet season,
(*c*) during the dry season.

Fig. 2 shows the percentage increases of the selected ten trees in each plot during the wet season (*i.e.* from November 14th to January 16th, 1942) and during the dry season (January 16th to April 30th).

The graphs illustrating percentage increase in height under differing shading assume roughly the expected parabolic form and in all cases show a point of inflexion at a definite shade intensity : shading below and above this point leads to decreased growth. The results for the wet season, the dry season and the total period all indicate that the optimum shade requirements for young cacao cuttings in Trinidad is roughly that provided by the three quarters canopy in this experiment. Observation of the plots and the state of the trees at the end of the experiment led to the same conclusion even more forcibly than do the measurements of height.

All the curves show a second lesser point of inflexion at about the 1/3 shade point which seems anomalous, but can be accounted for by suggesting marked differences in soil fertility between the 1/3 and ½ shaded plots. In observations prior to the experiment a definite falling off had been recorded in the general condition of the maize plants towards the south of the field and in the banana plants towards the east in the centre of the field. The ½ shaded plots happen to be so situated that they both lie in these poorer parts and there can be little doubt that poor soil accounts for the relatively poor growth on the half shaded plots. It is highly unlikely that 1/3 shading is more beneficial than ½ shading, given similar soil.

The curves in Fig. 1 demonstrate clearly the border effect between the plots. The curve relating to the total trees in each plot shows much less variation in growth under different degrees of shade than that for the selected ten trees from each plot, which were continually subject to the designed canopy. The adverse and variable border effect to which the guard rows were subjected naturally has a relatively greater effect on trees under the optimum canopy than on those with less beneficial shading.

The cuttings were planted towards the end of the wet season and the percentage increase curve shows that no very striking differences occurred in the rates of establishment and growth under the different canopies during the remaining two months of that season, though it is noteworthy and rather surprising, that even in that cloudy wet weather, three quarter shade was best. It was during the second part of the experiment, during the three-and-a-half months dry season, that the effect of shading became more marked, and in this case the optimum canopy is very

Table 1

Percentage Increase in Aggregate Heights under Differing Shade Intensities

Per cent. Increase.	SHADING				
	Plots D+G	Plots A+J	Plots F+I	Plots B+E	Plots C+H
	Full shade	¾ shade	½ shade	⅓ shade	No shade
Whole plots over whole period	42.54	53.21	41.33	45.75	21.90
Centre 10 trees : whole period ...	47.30	66.02	43.89	48.96	21.50
Centre 10 trees : wet season	15.31	18.29	12.68	14.39	8.75
Centre 10 trees : dry season	26.23	30.44	21.97	26.13	10.10

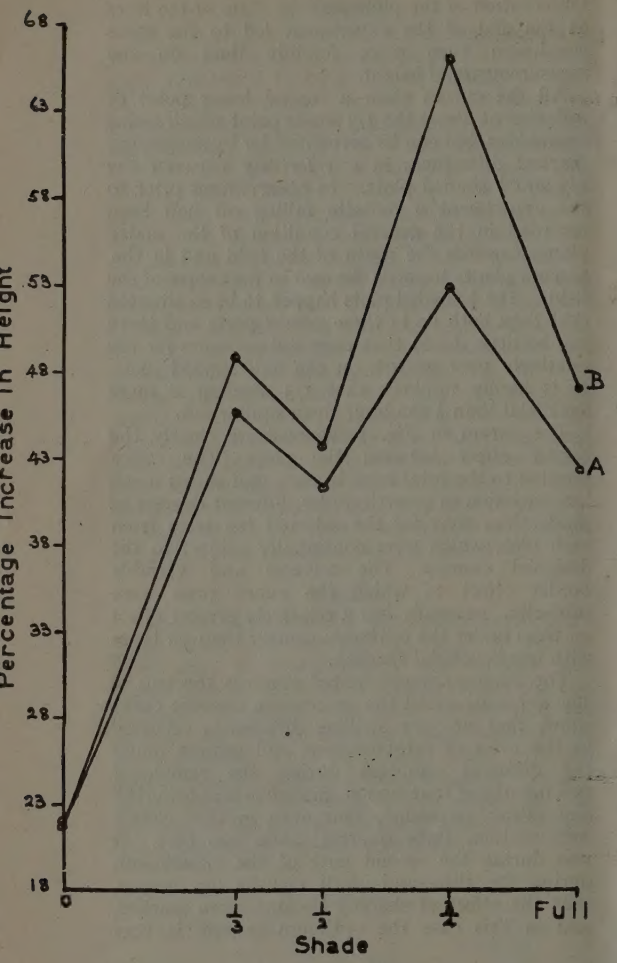


Fig. 1—Percentage increase in height of total trees (A) and ten selected trees (B) in each plot, over whole period.

definitely demonstrated, the increase in height under ¾ canopy being many times greater than that under no shade. At the same time all the curves show that cacao cuttings can be too heavily shaded; full shading had a depressing effect on the growth rate as compared to three quarter shade, in spite of the small size of the plots, and the rather large amount of diffuse light that consequently reached even the plants under full shade.

The state of flush of each tree was recorded each time the heights were measured. On all plots the period of flush of individual trees was found to be variable: on no plot was there any indication of uniform flushing at definite periods. Information in regard to flushing can thus only be presented by selecting examples from the various plots, and tracing the growth curve over the period of the

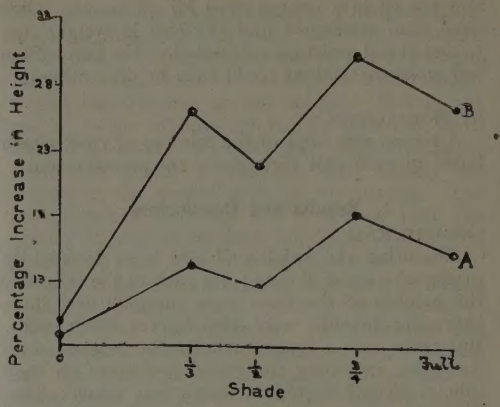


Fig. 2.—Percentage increase in height of ten selected trees during the wet season (A) and dry season (B).

experiment. Fig. 3 shows the history of two cuttings; one selected from the centre of plot A and the other from the centre of plot H, the former having the optimal three quarter canopy and the latter being unshaded. Cutting A showed a decreasing period of flush and an increasing amount of flush, whereas the unshaded cutting H gives a much smoother curve, with longer intervals between flushes and very much smaller amounts of flush. These curves are selected examples from the plots and only in a general way are they typical of the behaviour of the other cuttings in their particular plot.

Light Intensity Readings

Table 2 (*a*) consists of readings obtained by the Avo Lightmeter, taken at different places in each plot, at the height of the trees. A mean reading is obtained for each plot and thus a mean reading of the maximum light intensity transmitted be each canopy. Table 2 (*b*) gives the means results:—

Table 2 (b)

Canopy	Light int.
Full	4.0
¾	13.5
½	20.0
¼	28.0
0	78.0

Fig. 4 represents the percentage increase in height referred to the light intensity of the plots.

As the readings were taken during the middle hours of sunny days, they probably do not indicate very closely the optimum light intensity for growth

Table 2 (a)

Measurements of Light Intensity

Plots	Readings—in foot candles	Mean
A	18, 19, 20, 10, 13, 15, 10, 12, 11, 14, 20, 16	15.0
B	29, 30, 30, 29, 30, 31, 30, 31, 28, 30, 32, 31, 29, 30, 30	30.0
C	88, 89, 87, 91, 86, 88, 90, 87, 89, 88, 91, 85, 86, 88, 87	88.0
D	4.2, 3.2, 6.0, 4.0, 4.2, 4.6, 4.5, 6.2, 5.0, 6.0, 7.2	5.0
E	40, 19, 22, 22, 45, 18, 20, 25, 24, 30, 18, 20, 24, 27	26.0
F	21, 23, 23, 18, 28, 23, 22, 22, 20, 23, 25, 21, 22, 19	22.0
G	1.5, 1.0, 3.2, 3.9, 4.0, 2.8, 2.0, 3.2, 2.8, 4.6, 4.0	3.0
H	88, 80, 79, 60, 66, 59, 70, 68, 66, 80, 50, 50	68.0
I	17, 18.5, 20, 22, 16, 19, 18, 20, 17, 16, 18.4, 17	18.0
J	14.5, 10, 13, 7, 12, 11, 14, 13.5, 13, 12	12.0

of cacao cuttings. What they show is that optimum growth was attained where the *maximum* light intensity in the middle of a bright sunny day was between 10 and 16 foot candles. For older trees a different value might be obtained.

GROSS SOIL MOISTURE CONTENT

The mean results of the gross soil moisture content measurements under the five degrees of shading at the end of the dry season are shown in Table 3.

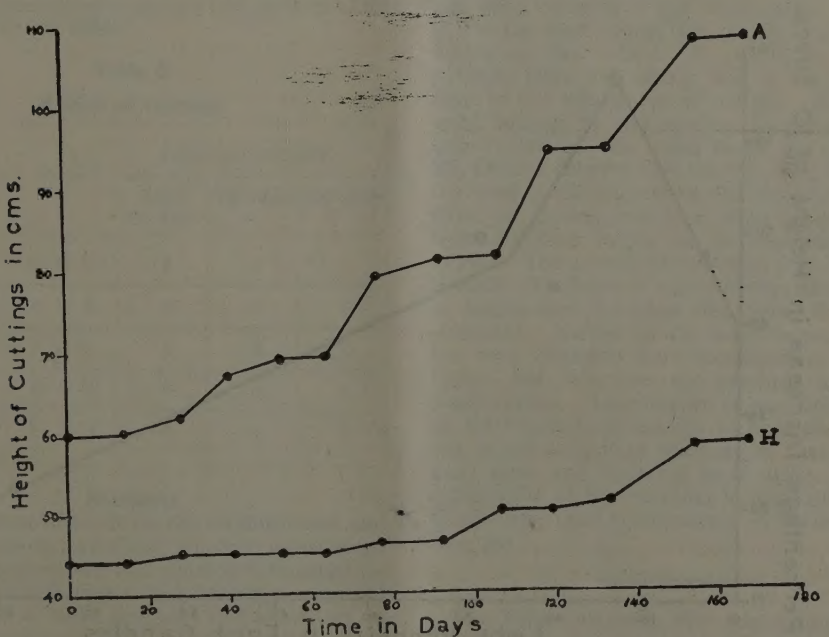


Fig. 3—Examples of flushing of cuttings from plot A ($\frac{3}{4}$ shade) and plot H (no shade).

Table 3

Mean Soil Moisture Contents

Shading	Plots	Soil moisture contents				Mean (%)
Full	D & G	15.96	17.44	18.71	16.25	17.09
¾	A & J	17.15	17.34	19.14	15.23	17.21
½	F & I	14.03	16.58	14.46	15.01	15.02
⅓	B & E	20.87	15.74	16.98	18.04	17.90
o	C & H	14.09	15.89	15.61	16.18	15.44

The difference between means is not significant. The considerable divergence in the state of the soil in different parts of the field has already been indicated, and this may account for the irregular soil moisture results. Other sets of results obtained at other times during the experiment also show no significant differences between the various plots, and not so large a variation as is shown by the above figures. The comparatively low value in the case of the half shaded plots may help to explain the relatively low value of the growth rate of cuttings on these plots.

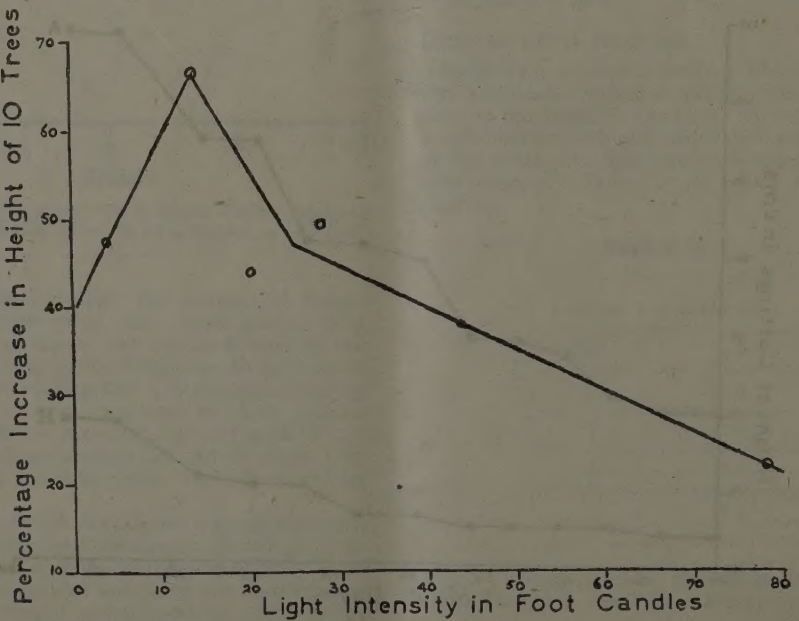
TEMPERATURE

The air and soil temperature measurements, taken throughout the course of the experiment are summarized in Table 4.

Table 4

Mean Air and Soil Temperatures

Shading	Plots	Mean air temp. in °C.	Mean soil temp. in °C.
Full	D & G	29.65	24.25
¾	A & J	29.90	24.70
½	F & I	30.55	25.25
⅓	B & E	30.75	25.50
o	C & H	31.30	25.90



ig. 4—Percentage increase in height under differing maximum light intensities.

It would seem highly improbable that mean differences in either air or soil temperatures of less than 1.5°C at the hottest time of the day could account for any large part of the great difference in growth between the plants in three-quarter shade and those in full sunlight.

Failure of Cuttings

During the investigation several of the cuttings failed to become established and were removed. In the first few weeks of the experiment these sites were supplied with new cuttings as is usual in estate practice, where 100 per cent. success is never realised. Later, however, certain cuttings which had appeared to have become successfully established lost their leaves and ceased flushing. They were then removed and their failure recorded. But observations throughout the experiment showed that cacao cuttings are very hardy, and cuttings planted in the unshaded plots showed an interesting development. Several of them failed from the start, but others, in spite of continued leaf fall, persisted in flushing, mainly from lateral buds. The leaves produced were small and very numerous and quickly hardened, later usually turning brown and falling. The guard row trees in the "no-shade" plots, which received shading during a part of the day were relatively quite successful, and a surprising number of even the cuttings which were subject to direct sunlight during the whole day succeeded in becoming established; though from their appearance at the end of the experiment it seemed unlikely that they would ever produce good trees. Table 5 gives the record of the failures. It will be seen that the plots with three-quarter canopy lost no trees at all after the first few weeks.

Table 5

Failure of Cuttings

Shading	Plots	Loss of Cuttings		
		After 21 days	63 days	168 days
Full	D & G	2	0	2
¾	A & J	3	0	0
½	F & I	3	0	0
¼	B & E	6	0	5
0	C & H	6	7	8

Summary

1. The effect of shade on the establishment and growth of new cacao cuttings has been investigated and it has been shown that shading is essential for successful establishment and growth, a careful provision of a three-quarter canopy leading to optimal growth and vigour. Under such a canopy the maximum light intensity on sunny days is 10 to 16 foot candles.

2. In the case of the optimal shading, the flushing of cuttings is rapid, and the period between flushes gradually decreases.

3. Whatever the canopy, a certain proportion of cuttings will always be lost at the outset but, in the case of a three-quarter canopy, cuttings that once become established will thrive.

4. Soil moisture content, and soil and air temperatures were investigated, but no significant or conclusive result was obtained. The differences observed were small and seemed to have little relation with the great differences in growth rates that were observed.

Acknowledgments

The writer wishes to acknowledge his indebtedness to Professor E. E. Cheesman, for his valuable guidance during the course of the investigation, and to Mr. G. E. L. Spencer for his assistance in planning and carrying out the experimental layout.

THE SARGASSO SEA

The problem of the origin and extent of th weed in the Sargasso Sea, which has long been debatable matter, is discussed by G. E. R. Deacon in a paper on the Sargasso Sea in the *Geographical Journal* (XCIX, No. 1). A century ago, Meyen argued that the weed grew as it drifted in the sea, that normal reproduction was vegetative and that the origin was in the Gulf of Mexico. Murray and Hjort did not subscribe to this theory; they believed that the weed would disappear if fresh supplies did not continually arrive from the coast. The weed certainly is not disappearing and there is not the least foundation for the statement of Tilden to that effect. It occurs in strips or patches, large and small, and is rarely out of sight in the whole area of the sea. Most of the weed belongs to two species, *Sargassum natans* and *S. fluitans*, but other forms are recognized. Mr. Deacon believes that there is little doubt that the weed is self-supporting, the total having been built up during centuries from plants drifted from the West Indies and by vegetative growth *in situ*. The annual contribution from the coasts is small. Evidence of vigorous vegetative growth, in leaves and branches free from Bryozoa, is abundant. Neither of the main forms, however, has been identified from the shores of the West Indies, but this does not preclude its original coastal origin. The absence of any field of weed on the coasts large enough to keep the Sargasso Sea as full as it is of weed shows that the weed must grow and multiply as it drifts, while the distribution of the currents is responsible for its accumulation and maintenance.—(*Nature*, Vol. 149 No. 3777.)

The Editor requests that any subscriber who fails to receive *Tropical Agriculture* regularly should communicate with him immediately in order that the matter may be rectified.

FACTORS AFFECTING FIELD YIELDS OF CACAO IN GRENADA

BY

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Introduction

The yields of some 23,000 pickets distributed over 26 cacao fields in Grenada have been recorded for the two crop years 1940-41 and 1941-2. The ultimate object of these records is to observe the effect of rehabilitation with cuttings. No cuttings have been planted up to the end of 1941-2 so that this and the previous crop can be used as control years for comparison. The records of these two crops have given ample evidence of the potential value of rehabilitation in Grenada and have been used to formulate programmes for individual fields. It is felt, however, that the records should also furnish more basic information regarding field performance which would give additional guidance in recommending rehabilitation policy.

It is impossible with only twenty-six fields, which have been intentionally selected for diversity so as to be representative of the industry of the whole island, to demonstrate satisfactorily the importance of factors determining yield by simple cross tabulation methods. It is, of course, possible with such data to show in tabular form the effect of a few predominant factors (such as the percentage of blank pickets in the field); but the effect has to be so obvious in the first place that little is to be learnt from such analyses. Further it is always unsatisfactory to attempt to show the simultaneous effect of two or more factors by cross tabulation. Thus, from the nature of the data these field records have been treated by more complex statistical methods. The statistics were first applied during 1941 to the 1940-41 yields (1). The results of the analyses were so unexpectedly satisfactory that it was decided to rework and extend the calculations on data averaged for 1940-41 and 1941-2. The results of the analyses of the two-year averages are presented in this article.

Factors affecting Yield

Shephard (2) and others have shown that the age distribution of pickets in Trinidad fields has a very important influence on yield per acre. The age distribution is itself a symptom of the effect of two prime causes—age of field and soil type. Indeed, although no precise calculations have yet been made for Trinidad it appears that age of field, soil type and the interaction of the two are the basic determinants of field yields in this island.

In the analysis of Grenada data therefore, these two factors were taken into consideration; but there is also another factor—manuring—which is recognised as important by planters and investigators in Grenada. It should be noted that any index of manuring will also include certain cultivation operations, chiefly forking, which are performed at the time manures are applied. Thus a field of high manurial status will be one with relatively intense cultivation particularly as regards forking.

Other possible factors were also contemplated but it was found difficult to isolate any other important one from a network of relatively unimportant interactions. For instance, next in importance after soil, age and manuring is probably rainfall, but its effect is modified by variation in the soil features, the drainage and the gradient of a particular field, by the amount of exposure to sun and wind, to the distribution of the total fall and so on. All these minor factors should be taken into account simultaneously to obtain a clear (or probably significant), effect of rainfall on yields. The simultaneous solution of six unknowns is laborious but accurate solution of seven or more which would be required to study rainfall as an additional factor would be impossible with standard calculating equipment.

Measurement of Independent Variables

Even with only the three factors, soil, age and manuring, certain difficulties arise in expressing all of these factors in quantitative terms. It is obviously necessary to consider these three factors simultaneously so that if, for instance, there is a tendency for old fields to be more heavily manured than young ones the independent effect of each factor will not be masked or exaggerated by the effect of the other. An analysis of this nature can be made by the calculation of partial regression coefficients for which it is necessary to express all factors as quantities. The age of field is, of course, an easily measured quantity but the intensity of manuring even over a short period of time is difficult to express quantitatively because of the different kinds and combinations of manures applied. Soil type also is essentially a difference in kind until the actual difference in yield due to type has been measured. Thus, to reduce the manuring and soil factors to quantitative terms, certain approximations had to be made.

It was observed from the data that the fields on one soil type (Lateritic) which from chemical analysis over a range in depth appeared to be of low fertility were on the whole heavily manured and gave yields almost as high as fields on the most fertile soil type (Alluvial).

Table I

Average Yields of Fields by Soil Types (1940-41) (Unadjusted for Manurial Status)

Soil Type.	Index of Manurial Status.*	Lbs. per Acre.	Lbs. per Picket.	Lbs. per Mature Tree.	Number of Fields.†
Lateritic	+ 50	975	2.4	2.9	8
Brown Earth ...	— 8	800	1.8	2.4	7
Sandy Lithosol	— 66	788	1.9	2.6	5
Alluvial...	+ 15	1,090	2.5	3.6	4

* For assessment of manurial status, see text below; extremes of manurial status of individual fields were ranked plus or minus 195 respectively.

† Two exceptional fields, in which extensive cutting of cacao for banana production was made, have been omitted from all calculations.

It is obvious from Table I that some adjustment for manuring must be made before any quantitative index can be assigned to soil type.

There is no way of measuring the diverse manurial applications employed on these fields except perhaps on a rather unsatisfactory monetary basis; it was considered more advisable merely to rank fields in approximate order of intensity of manuring. The ranking of fields was based on records of manurial applications for the past five years and scores were allotted to ranks according to a normal distribution of 24 variates (3).

A simple regression was then calculated for yield per mature tree on these manurial ranks and a highly significant regression was obtained; (the F test at the 1 per cent. point required a ratio of 1 to 7.94 while 1 to 9.38 was obtained).

The yields per mature tree in each field could therefore be adjusted by this regression and the adjusted yields by soil type averaged as follows:

Lateritic .... 2.6 lbs. per mature tree.
Brown Earth .... 2.5 lbs. ,, ,,
Sandy Lithosol 3.0 lbs. ,, ,,
Alluvial .... 3.6 lbs. ,, ,,

For average manuring then, the Alluvial soil is the most productive type but the Sandy Lithosol is second; there seems to be little difference between the Lateritic and the Brown Earth. Because of the similarity of these latter two types from the productive point of view and because of the approximations introduced in adjusting for manurial status, it was considered adequate merely to rank the types in three classes between which marked differences in yield occurred. The scores allotted to each class were: Alluvial +1; Sandy Lithosol 0; Lateritic and Brown Earth −1.

In this way three quantitative factors which are suspected of influencing yield were obtained, all of which will be represented by linear regression lines. It is however doubtful if a linear regression of yield on age of field will give adequate representation of the relationship since it is generally accepted that fields increase in yield up to a certain age and decline thereafter. If this is actually the trend a linear regression may seriously underestimate the dependence of yield on age of field. To safeguard against such underestimation a fourth independent variable (the square of the age of field) was included in the calculations.

Partial regression coefficients of the 1940-41 yields on these four factors accounted for a surprisingly large amount of the variation in yields; so large indeed that some unconscious bias was suspected. It was thought possible that bias had been introduced in ranking fields particularly according to manurial status on which of course the soil ranking partly depended. It was necessary in placing the fields in order of manuring to use some judgment and since the actual 1940-41 yields were already known when the ranking was carried out it was possible that manurial status was unconsciously overestimated in high yielding fields. To eliminate this bias as far as possible the data for two crops were averaged and the regressions recalculated on average data. It is fortunate that there was a large seasonal difference between 1940-41 and 1941-2 and that fields were differentially affected to quite a marked degree.

On comparing the calculations common to both sets of data no great differences were found; actually on the whole more of the variation in yields was accounted for in the two-year than in the original one-year results, and it seems unnecessary therefore to give both of them in this article.

Effect on Yields

On the two-year data the following yield factors were considered:

(i) Yield per acre.
(ii) Yield per picket.
(iii) Yield per tree.
(iv) Yield per bearer.
(v) Yield of original trees.

The first four factors are calculated from the total field yields, the last one from the total yield of original trees (*i.e.* trees surviving from the original planting) only. The combined effect of the four independent factors (age linear and quadratic, soil type and manuring) was shown to be significant by the F test as follows:

	F
(i) Yield per acre	.... 1 : 3.7
(ii) Yield per picket	.... 1 : 4.2
(iii) Yield per tree	.... 1 : 4.7
(iv) Yield per bearer	.... 1 : 9.0
(v) Yield of original trees	.... 1 : 9.6
Significant at P = .05 ($n_1 = 4$ $n_2 = 19$)	.... 2.9

It is obvious also that these four factors have a far more definite influence on the yield per bearer and on the yield of original trees than on the other yield factors. This immediately leads to the conclusion that the percentage of blank pickets and other non-bearers are not influenced appreciably by age of field, soil and manuring.

Table II

Significance of Partial Regression Coefficients
(t=2.09 at P=.05 and d/f=19).

	Manurial Status.	Age of Field.			Soil Type.
		Linear.	Quadratic.	Combined.†	
(i) Yield per acre ...	2.97*	.79	.58	1.16	2.07
(ii) Yield per picket ...	3.31**	1.31	1.10	1.50	1.53
(iii) Yield per tree ...	3.12**	2.01	1.80	2.32*	1.73
(iv) Yield per bearer	4.03**	2.42*	2.16*	2.84*	3.04**
(v) Yield of original trees	3.34**	3.12**	2.70*	3.92**	3.17**

† The combined significance of the two age factors was calculated from the variation accounted for by the age and the residual unaccounted for by the four independent variables. For 1 degree of freedom in the variance to be tested $t=\sqrt{F}$.

The significance of the partial regressions individually is given in Table II.

Significant partial regressions are obtained for the effect of manuring on all the sets of yield figures; it is also clear from the Table that manuring has the most definite effect of the four independent factors. On the other hand soil type has a significant effect only on the yield per bearer and of original trees. The same is true of the effect of the two individual age factors but if these two are combined it is found that the yield per tree is also significantly affected by age of field.

The magnitude of the manurial regressions can best be shown by grouping the data into three manurial classes of an equal number of fields and from the average manurial status of each calculating the mean yield of each class. The results are given in Table III.

Table III

Effect of Manuring (previous 5 years) on Yields (Adjusted for Age of Field and Soil Type)

Lbs.	Manuring.		
	Heavy.	Medium.	Light.
Number of Fields.	8	8	8
(i) Yield per acre* ...	795	783	771
(ii) Yield per picket*	2.19	1.87	1.55
(iii) Yield per tree* ...	2.59	2.25	1.91
(iv) Yield per bearer*	2.83	2.46	2.09
(v) Yield of original trees* ...	3.11	2.77	2.43

* Yields calculated on significant partial regression coefficients.

Table IV gives figures calculated in a similar manner for yields according to three soil classes. It is evident that, although soil type does not have such a consistent influence on yields as manuring as shown by the relative significance (Table II), the soil effect for average manuring and field age that does occur is of about the same magnitude as the manuring effect for the groupings adopted. It must be concluded therefore that there is inherently a marked difference between soil types

Table IV

The Effect of Soil Type on Yields (Adjusted for Age of Field and Manuring)

Lbs.	Mean Yield.	Alluvial.	Sandy Litho-sol.	Lateritic and Brown Earth.
Number of Fields.	24	4	5	15
Yield per acre*...	783	796	787	778
Yield per picket*	1.87	2.10	1.94	1.78
Yield per tree*...	2.25	2.56	2.35	2.14
Yield per bearer	2.46	2.90	2.60	2.30
Yield of original trees	2.77	3.28	2.93	2.58

* Yields calculated on non-significant partial regressions.

which at average levels of manuring is upset by topographical, climatic and other factors which have not been taken into account in these calculations. On the other hand, the effect of manuring (including certain cultivation operations which our manurial ranks include) is not so much masked by these factors. These data therefore show that manuring and cultivation have been successfully used to reduce disadvantages of topography and climate.

The effect of age of field can most conveniently be shown in graphical form, the method of calculating the curves being the same as that employed to construct Tables III and IV. The curves are shown in Figure 1. For clarity of representation a yield per acre curve has not been included since the yields are of such different magnitude from those shown in the Figure. A curve for yield per acre drawn on a comparable scale is very similar to that for yield per picket, because there is little variation in planting distance, the average being about 10 by 10 ft.

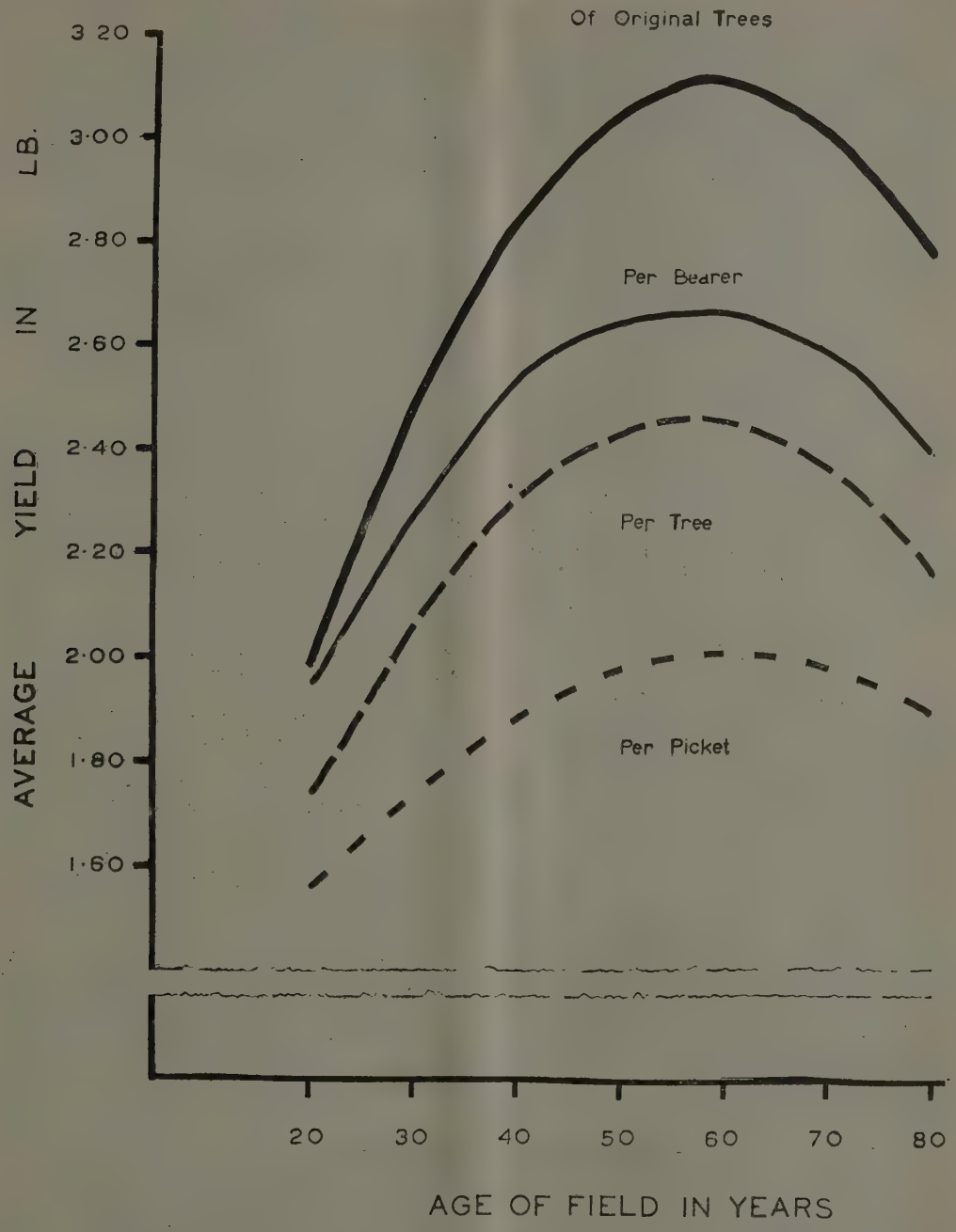

FIG. 1.—Regressions of Yields (adjusted for Soil and Manuring) on Age of Field.

It is clear from these curves that age of field has a big effect on yields; in the case of yield per original tree the difference in yield between field ages of 20 and 60 years is as much as 1 lb. per tree. The curves also bring out the point that considerable curvature occurs and that maximum yields occur in fields of about 60 years of age (that is for average manuring and soil type). Up to that age there is a relatively rapid increase in yields and afterwards (except with original trees) a more gradual decline. It is striking that the yields of young fields are low; the general impression obtained from Trinidad fields is that maximum yields are obtained at 25 to 30 years of age;

clearly this is not the case in Grenada. This difference between the two islands may tentatively be attributed to manuring as an aid to soil fertility. Apparently in Trinidad a process of soil exhaustion continues from the time of planting, whereas in Grenada it would seem the soil fertility is gradually built up by manuring and evidently does not reach its maximum for a very considerable time. If this is the true cause of the increase in yields in Grenada, it suggests that a concentration of manuring and cultivation in the early life of the field in order to build up fertility quickly would be a profitable proposition. This suggestion is emphasised by the evidence of high tree mortality at, and soon after, planting (*see* below).

The Effect on Field Populations

The differences observed in the regressions of various yield data can be concisely and more practically expressed in terms of field populations. For instance, there is a marked difference in the regressions for yields per picket and yields per tree; the difference is, of course, due to the distribution of blank pickets which by implication is not closely correlated with the independent factors—age of field, manuring and soil type. Further regressions have been therefore calculated for the three dependent factors :—

(vi) Percentage of blank pickets.
(vii) Percentage of non-bearing trees.
(viii) Percentage of original trees.

The significance of the combined effect of the four independent variables is as follows :—

	F.
(vi) Percentage of blank pickets	1 : 0.5
(vii) Percentage of non-bearing trees	1 : 1.4
(viii) Percentage of original trees	1 : 10.7
Significant at P= .05 (n_1=4, n_2=19)	1 : 2.9

There is a very striking contrast between the significance with the first two dependent variables, both of which are markedly non-significant and the third, the percentage of original trees, which is more significant than any of the other seven sets of regressions so far calculated. The significance of the individual partial correlation coefficients is given in Table V.

The interesting point of the first two lines of the Table is the very low significance of manuring on the percentage of blanks and of soil type on the percentage of non-bearers; the significance is so low as to give almost a proof that no correlation exists between the variables; these two *t* values indicate a probability of about .85 for manuring and blanks and .75 for soil type and non-bearers that *no correlation* exists.

It may be thought that these results conflict with general field experience in that they indicate (*a*) that manuring will have no effect in establishing and maintaining a good stand of trees and (*b*) that the more productive soil types do not carry fewer non-bearing trees. It appears that these two points require further discussion.

With regard to the first point it should be emphasised that the manurial status is based on manuring for the past five years only. If many tree casualties have occurred more than five years previously (and it will be seen below that newly planted fields are probably most liable to casualties) the current manurial status could not be closely correlated with the percentage of blank pickets that have accumulated over the whole life of the field. It may quite rightly be argued on the other hand that differences in manuring are permanent features of the management of different estates and that a field which at present is well manured has probably been well manured for considerably more than five years previously. If our manurial indices do on the whole apply for a longer period we must conclude the fertility of the fields when planted is not correlated with the final manurial status and that the casualty rate in the first few years of the life of the field depends more on inherent soil fertility, shade conditions, etc., than on our final manurial status. In short that the soil fertility is built up by manuring from a variable initial level; the consistent increase in field yields from 20 to 60 years is also evidence that artificial fertility is increasing due to manuring during this period. This regression therefore indicates that it is sound policy to plant young supplies in existing fields in which fertility has already been accumulated by manuring and cultivation.

Table V.

Significance of Partial Regression Coefficients

(t=2.09 at P=.05 for 19 d/f).

	Manurial Status.	Age of Field.			Soil Type.
		Linear.	Quadratic.	Combined.	
Percentage of blank pickets ...	.19	1.26	1.28	1.08	.46
Percentage of non-bearing trees ...	.85	1.88	1.72	1.96	.31
Percentage of original trees ...	2.46*	1.42	.66	4.96**	1.38

The second point—the lack of connection between the percentage of non-bearing trees and soil type is important in showing variation in the management of estates. A large proportion of these non-bearing trees are immature supplies (40 per cent. below 15 years of age). The percentage of non-bearers therefore indicates the extent of supplying; and there is evidently a large amount of variation in supplying, unaccounted for by fertility factors such as soil type and manuring. The regression for manuring and the per cent. non-bearers is admittedly higher than for soil type, but we must remember that intensive manuring included intensive cultivation which will itself to some extent include the intensity of supplying; so what correlation exists between manuring and surviving supplies is probably not directly associated with fertility. From practical observation it is safe to say that the variation in the percentage of non-bearers is associated with estate managerial policy; many managers do not attempt regular supplying of their fields while even those that do, achieve very variable success in proportion to the attention that is given to the young trees after they have been planted.

The regression coefficients of manuring and soil type and percentage of blanks and non-bearers are very small (less than 2 per cent. for the extreme classes given in Tables III and IV).

The effect of these two factors on the percentage of original trees is larger and manuring is significant:

Manurial Status	Per cent. of Original Trees
Heavy	58.6
Medium	52.7
Light	46.8

Soil Type	Per cent. of Original Trees
Alluvial	47.6
S. Lithosol	51.1
Lateritic and Brown Earth	54.6

It is at first surprising that the best soils should have the lowest percentage of original trees but actually the explanation is simple and of interest. The Lateritic and Brown Earth soils are the heaviest in physical texture, the Alluvial the lightest. Undoubtedly a major cause of tree casualties in Grenada is exposure to drought and wind during the dry season; thus the light soils, which are naturally fertile and can produce good crops (coming, of course, mainly from wet season growth) are liable to damage from excessive drought. More shade trees in fields on these light soils might be an improvement and a method of making better use of the most productive soil types.

The effect of age on the three percentages is given in Figure 2. No particular importance is to be attached to the two lower curves since they are both insignificant; the form of the curves fits expectations reasonably well. The greatest importance, however, is to be attached to the curve for the percentage of original trees, since a high degree of significance has been obtained. (The reason for the low significance of the partial regression coefficients is purely technical and cannot be fully explained in this article; the combined effect of age should be the one to consider in judging this regression.) It will be remembered that original trees give the highest yield of any group of trees or pickets in a field (Fig. 1) and the decline in field yields after 60 years is undoubtedly due to the continuous casualty of original trees. This casualty rate can be checked by manuring; but from the high significance of age, it evidently cannot be counteracted. Old fields therefore are less productive than young ones rather because of than in spite of the small number of old trees.

The curve of the percentage of original trees further confirms the supposition that the casualty rate in young and newly planted fields is high. Even over the range of field age shown in the figure, the casualty rate (the slope of the line at any point) is greater in the young than the old fields. Outside the range of the data this particular curve would not fit, since fields at the time of planting (0 years of age) would have only 84 per cent. of originals; obviously a higher mortality rate occurs up to 20 years of age than the data for fields of over 20 years indicate.

The Effect of Age on the Yield of Original Trees

It has been seen (Table II) that the yield of original trees is very significantly dependent on soil, manuring and age of field. Further that age of field (and therefore in this particular case, age of tree) alone is very significant; that yields increase rapidly up to 60 years and decline thereafter, equally rapidly. This trend raises a question of economic importance and of interest to the plant physiologist as to whether the form of the curve chosen gives an accurate representation of the real trend. If the trend is in fact steeply downward the trees are rapidly becoming senescent and should be removed when the field reaches 90 to 100 years old.

There is, however, a possibility that the form of a quadratic curve is not well suited to the data. The ultimate downward trend may be due to the nature of the curve itself and not so much to a trend in the data. This possibility is increased by the fact that there are only four fields out of the 24 over 60 years of age. A poor fit over the age range 60 to 80 years would not appreciably decrease the goodness of fit throughout the whole.

It therefore seemed desirable to calculate a more complicated curve for the yield of originals on the age of field; it is necessary that the curve should be of such a nature as to accommodate all reasonable shapes and trends. A polynomial regression, taking the first five powers of age of field, was calculated for the yield of original trees after adjusting them for manuring and soil type according to the four factor partial regressions

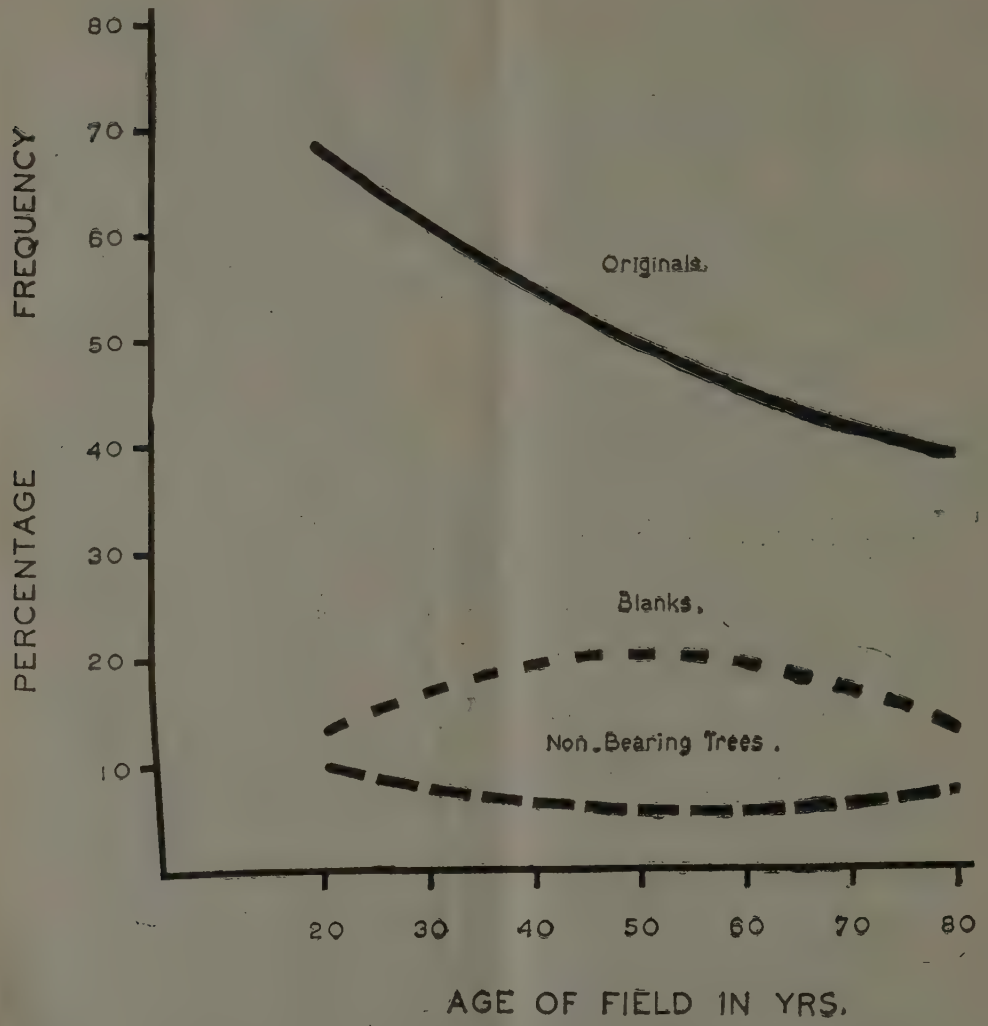

FIG. 2.—Regressions of Field Populations (adjusted for Soil and Manuring) on Age of Field.

already calculated. This polynomial curve fitted the data appreciably better than the two power curve: 46 per cent. of the adjusted yield variation was accounted for by the two powers of age, giving an F ratio of 1 : 4.6 (age considered as a single factor); the polynomial curve accounted for 61 per cent. of the yield variation and gave an F ratio of 1 : 11.6 (age still considered as a single factor).

The polynomial curve shown in Figure 3 is apparently similar to the quadratic curve shown in Figure 1. The differences between the curves and the reasons for the better fit of the polynomial are: the more rapid increase in yield up to about 40 years field age; and the longer period of about maximum yield, that is with yields between 3.0 and 3.1 per original. This polynomial curve emphasises the observations made on the quadratic curve and particularly on the rapid increase in yield up to 40 years of age.

Conclusions

The statistical analysis of these Grenada fields helps very considerably to obtain a picture of conditions of production in the island. It is striking that a large amount of the yield variation can be accounted for by the three factors, age of field, soil types, and manurial status. The combined influence of these four factors accounted for from 44 to 67 per cent. of the yield variations (sums of squares). The conclusion is that the numerous other factors affecting yield do not

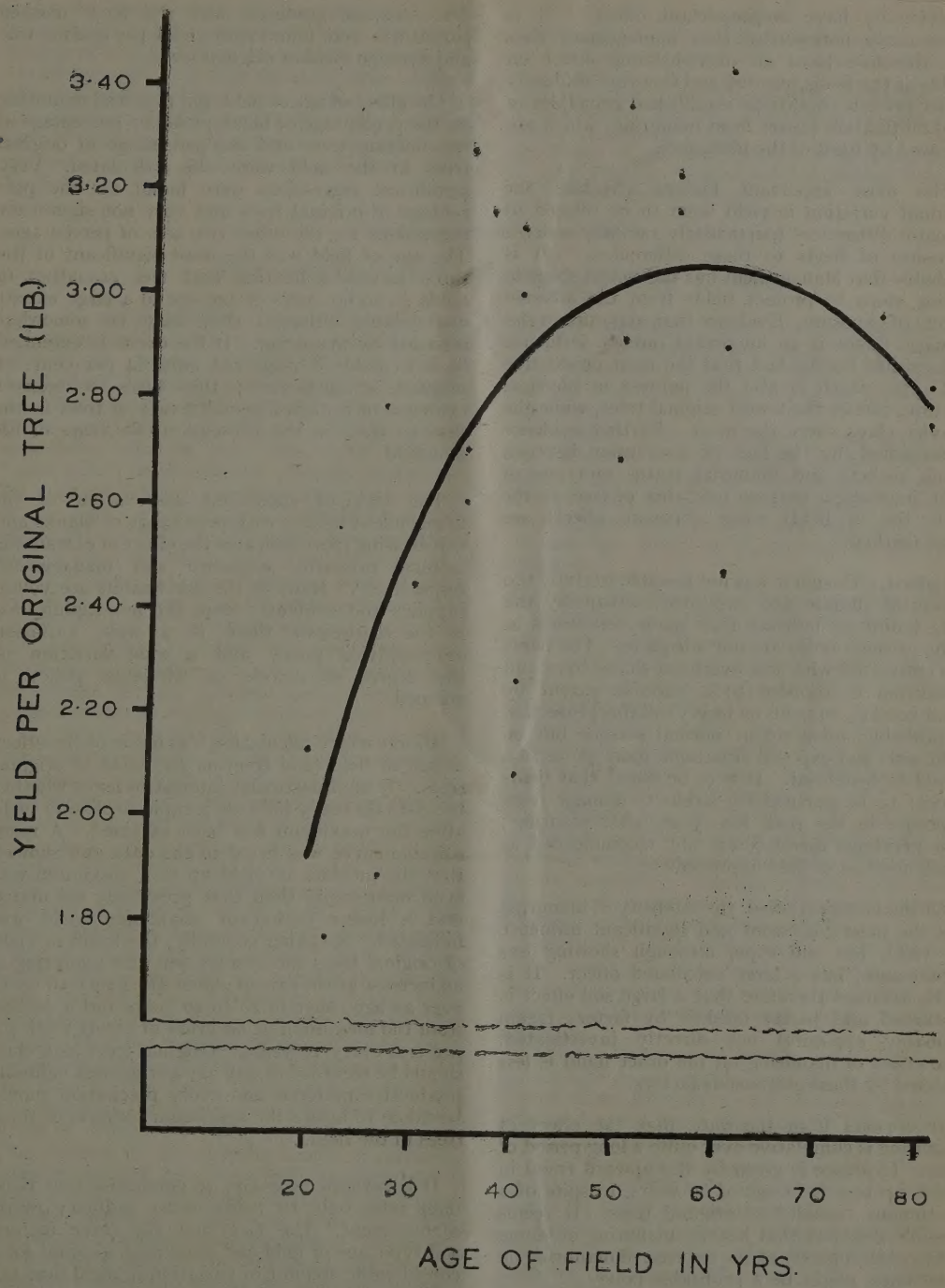

FIG. 3.—Polynomial (5 Powers) Regression Curve of Yield per Original Tree (adjusted for Soil and Manuring) on Age of Field.

individually have an important effect. It is particularly noteworthy that management does not therefore have an overwhelming effect on yields of the fields selected and there are evidently under present conditions established principles of field cultivation (apart from manuring) which are followed by most of the managers.

The most important factors affecting the residual variation in yield seem to be related to climatic differences (particularly rainfall) and the exposure of fields to these differences. It is probable that Management has the widest scope in taking steps to protect fields from the adverse effects of exposure. Evidence that exposure to the climatic factor is an important outside influence is furnished by the fact that the most productive soil type, which is also the lightest in physical texture, carries the fewest original trees, while the heavier clays carry the most. Further evidence is furnished by the lack of association between blank pickets and manurial status and age of field, implying a varying mortality of trees in the early life of fields when exposure effects are most marked.

Indeed, although it was not possible to study the effects of climate and exposure statistically the data indirectly indicate that shade conditions in some of these fields are not adequate. The fields are cultivated with few overhead shade trees and protection is afforded to a variable extent by wind-breaks ; in fields on heavy soil this protection is probably adequate in normal seasons but on light soils and exposed situations more protection would be beneficial. It is to be noted that fields appear to be particularly liable to damage from exposure in the first few years after planting ; new plantings therefore are not recommended as a safe method of field improvement.

Of the factors studied, the intensity of manuring has the most consistent and significant influence on yield, but soil type, although showing less significance, has a large calculated effect. It is to be assumed therefore that a large soil effect is disturbed and partly masked by factors (again probably exposure) not directly investigated. The effect of manuring on the other hand is less affected by these extraneous factors.

It appears from the data that the effect of manuring is cumulative over quite a long period of time. Evidence is given by the upward trend in yields up to a field age of 60 years, in spite of a continuous casualty of original trees. It seems possible therefore that heavier manuring of young fields, even if partly at the expense of manuring on older ones, might be a profitable policy.

The age of field has a significant influence on all yields except yield per acre and yield per picket. The trend in all yields (according to the quadratic curve fitted) was an increase up to field age of about 60 years of age and a decline thereafter. The steepest gradients and the most marked curvatures were found with yields per bearing tree and average yield of original trees.

The effect of age of field, soil type and manuring on the percentage of blank pickets ; percentage of non-bearing trees and the percentage of original trees in the field were also calculated. Very significant regressions were found for the percentage of original trees and very non-significant regressions for the other two sets of percentages. The age of field was the most significant of the three factors indicating that tree casualties in fields 20 to 60 years of age are to a large extent unavoidable although they may be somewhat retarded by manuring. If the curve is extended back to fields 0 years old only 84 per cent. of originals are indicated ; thus there is indirect evidence of a higher casualty rate of trees in the first 20 than in the subsequent 60 years of life of a field.

The lack of significant association of the independent factors with percentage of blanks and non-bearing trees indicates the effect of extraneous factors, primarily exposure and management respectively. Many of the non-bearers are young supplies and evidently from the non-significance of the regressions there is a wide variation in supplying policy and a wide variation in the degree of success of whatever policy is pursued.

A more exact calculation was made of the effect of age of field (and tree) on the yield of original trees. It is of particular interest to learn whether the data do really indicate a rapid decline in yield after the maximum has been attained. A more suitable curve was fitted to the data and showed that the increase in yield up to a maximum was even more rapid than that previously calculated and a longer period of maximum yield was indicated. Speaking generally, the trend in yield of original trees for average soil and manuring is an increase at the rate of about ½lb. every 10 years over an age range of 20 to 40 years and a decline from the maximum at 60 years of about 1/5th lb. per tree every 10 years. Original trees as a class should be regarded at any age as the most valuable productive material and every precaution should be taken to insure the maximum survival of these trees in the field.

It is perhaps necessary to emphasise that these data refer only to fields under ordinary estate management. The fact that the three factors, soil type, age of field and manuring, account for a considerable amount of variation in yield does not indicate that the scope of management *need necessarily* be confined to the execution of a sound manurial policy ; the analyses merely indicate that the scope of management is at present confined in this way under existing methods of field cultivation. There is undoubtedly wide

scope for higher yields by the adoption of new methods of field management: by the use of improved planting material and the practice of a systematic policy of field rehabilitation. Indeed, the uniformity of the data indicates that the existing system within itself offers little scope and that if yields are to be improved appreciably new methods of field management will have to be applied.

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THE NUTRITION OF VEGETABLE CROPS

In an article entitled "Some Aspects of the Nutrition of Vegetable Crops" published in the *Annals of Applied Biology*, Vol. 29, No. 2, T. Wallace considers the following as essential conditions for the successful cultivation of vegetables:—(1) There must be a good depth of soil and there must be no "pan," due either to "iron pan" or mechanical packing of the soil; (2) drainage must not be defective at any season of the year; (3) soil reaction should be slightly above pH 6.0 and a small reserve of carbonate of lime is generally desirable; (4) there must be a plentiful supply of organic matter, some of which should be in a state of active decomposition; and (5) plant nutrients, especially nitrogen, phosphates and potash, must be present in adequate amounts. Other nutrients such as calcium, magnesium, iron, manganese, boron, sodium and chlorine also present problems of practical importance.

The large requirements of brassicae for major nutrients are shown in the results of Vanstone and Knapman (1939)* for broccoli crops grown in Devon and Cornwall, where the following average amounts per acre were removed from the soil: N 204 lb.; P_2O_5 70 lb.; K_2O 240 lb.; CaO 110 lb. These compare with values for wheat grain and straw quoted by Vanstone and Knapman from Comber: N 60 lb.; P_2O_5 20 lb.; K_2O 30 lb.; CaO 10 lb. Lewis (1938) also estimated that in his experiments a crop of Brussels sprouts removed 300 lb. N/acre. Results such as these for many kinds of vegetable crops emphasize, in particular, the very large requirements of vegetable crops for nitrogen and potash, this great need for potash often not being realized by growers and technical officers who have been used to farm crops. Vegetable growers are fully aware of the importance of the liberal application of nitrogen to their crops, but opinion is often divided on the relative merits of different forms of nitrogen for use on various crops and a sharp distinction is drawn between organic and inorganic fertilizers. This last point is of some importance at present since supplies of "organic" nitrogenous materials are very short and may be curtailed still further during the period of the war. Even if growers must rely wholly on inorganic sources of nitrogen, mainly sulphate of ammonia, there is no reason why success should not be achieved with most crops. Salad crops, such as lettuce, and the 'timing' of crops may present difficulties.

Vegetable growers invariably use phosphates very liberally and old market garden soils show very large amounts of 'available' phosphate. Whether such liberal use is sound practice requires investigation and possibly economies in the rates of dressings could be made without sacrificing efficiency.

Manurial Requirements of various vegetable crops

BRASSICAE: cauliflowers, broccoli, kales, cabbages, savoys, Brussels sprouts. Provided land is in good heart and contains a reserve of lime, yields can be kept at a high level by liberal nitrogenous manuring.

ROOT CROPS: carrots, parsnips, beets, turnips. Carrots and parsnips, and to a less extent beets, seem to have higher requirements for potash than most vegetable crops (Dyer *et al.* 1913).* Carrots are a priority crop for potash. Salt may be used to replace potash for beets and trials might also be made with carrots and parsnips. Beets should not be overlimed. Turnips succeed under fairly low potash conditions. Turnips need rich soil when grown for human consumption.

LEGUMES: peas, broad beans, French beans. These crops should not be attempted on land deficient in potash and should be given a high priority by the grower for any potash supplies he may have.

ONIONS: Onions as a priority crop appear to have a high potash requirement (Dyer *et al.* 1913). Onions seem generally to fail on newly ploughed grassland and it is not clear how far this is due to unfavourable potash conditions. Leeks should also be given some potash when possible and it is most important that they be given a priority by the grower for bulky organic materials.

LETTUCE AND SPINACH: Lettuce needs land in a high state of fertility. It often fails on newly ploughed up grassland. Potash is important. Organic forms of nitrogen appear better than inorganic forms. Provided spinach is planted on land in good heart, the great need is for nitrogen.

* Vanstone, E. and Knapman, C. E. H. (1939). On the quantities of nitrogen, phosphonic acid, and potash and lime removed from the soil by a crop of Roscoff broccoli during its growth.—*J. Pomol.*, 17, 85.

* Dyer, B. and Shrivell, F. W. E. (1913). The manuring of market garden crops, London, Vinton and Co., Ltd.

CHEMICAL NOTES

(Compiled by the College Department of Chemistry and Soil Science)

Further Notes on Coffee Manuring

These notes published in the *Mon. Bull. Coffee Bd.* Kenya, 1942, 7 : 22-3, refer more especially to the manuring of coffee in Kenya under wartime conditions. Sources of nitrogen other than sulphate of ammonia are discussed. The basis of manuring should be the preparation of the maximum amount of farmyard manure and the method of preparing this to the best advantage is described. Meat meal and bone meal is available. Comparable applications would be 150 lb. per acre of blood meal, meat meal or hoof and horn meal, 250 lb. carcase meal, 170 lb. carcase meal mixed with 50 lb. of any of the first mentioned materials and 150 lb. of bone meal similarly mixed with 100 lb. of the more nitrogenous materials. A light cultivation should follow the application of any of these. Cotton seed can be applied at the rate of ¾-1 ton per acre. It would need to be buried deeply enough to prevent germination and 1/6 to 1/8 the normal bulk of farmyard manure would be required in addition to provide sufficient nitrogen to equal that of the meat manures if this is considered necessary. Supplies and prices are discussed. For phosphatic fertilizers bone meal or Seychelles phosphate are still both procurable. Bone meal must be worked deep into the soil. 1 cwt. per acre every other year should be enough on land previously kept well manured. Potassic fertilizers cannot now be imported but the Kenya coffee soils mostly require none. In certain lighter and more acid soils wood ash at the rate of ½-1 ton per acre can be broadcasted.

* * *

Applicability of Mitscherlich Method to Determination of Available Phosphate

A new method of applying the Mitscherlich technique to determine available phosphate in Iowa soils is described by Hoover and Norman in *Soil Science*, Vol. 53, No. 5. These workers found that the "effect factor" (*c*) in the Mitscherlich equation varies with the variety of oats used, and suggest that it may also vary with season, different fertility levels, and different environmental conditions. They obtained values for "c" which ranged from 3.51 to 1.68 as compared with Mitscherlich's value of 1.95. In order that maximum value would result from the application of the Mitscherlich method, they decided to determine the effect factor with each experiment carried out. This was done by including in each experiment three sets of replicates each receiving 0.1, 0.2 and 0.3 g. P_2O_5 respectively. The yields obtained from these applications would delineate the lower part of the yield curve. The maximum value "A" could be calculated by assuming a logarithmic response curve, or could be determined experimentally by addition of three extra pots, each receiving 1.0 g. P_2O_5, which is the amount calculated by Mitscherlich to give maximum yield for phosphate.

* * *

The Ideal Soil

The ideal soil is not composed of discrete mineral grains, but of crumbs or aggregates. These include colloidal matter of two kinds—mineral colloids and organic colloids. The latter may be partly humus, which may be regarded as an *end-product* of the microbial decomposition of organic matter. In a fertile soil, the organic matter includes a sticky material less inert than humus, and resulting from the recent decomposition of organic matter. This organic cement sticks the grains together into small crumbs which have the most desirable physical properties. It is not the microbes which are important in soil, but the products of their recent activity are important.

There is reason to believe that the plant and the soil with which it is in contact form a practical continuum. This contention gains weight from the work by H. Jenny and R. Overstreet on ionic exchange.

If plants are grown in mixtures of sand and calcium clay, the roots accumulate calcium ions, whereas the clay particles gain in adsorbed hydrogen ions. Contact exchange is postulated to take place only when the (cation) oscillation spaces of particles overlap; the particles may be both clay, or one may be a root surface, both being negatively charged. Contact intake is difficult to investigate on account of a presumed high gradient of carbon dioxide in the neighbourhood of a root, but there is very suggestive evidence of contact depletion, so that the theory of contact exchange of ions may be regarded as having made a promising beginning. There is yet no evidence for contact exchange of anions. No contact jumping of cations could be found between roots and positive iron hydroxide sol.

The disposition of materials by plants is a highly dynamic and largely cyclic set of processes. There are, of course wheels-within-wheels: short-period cycles as well as long-period cycles. The broad cyclicity of nutrients is well shown in the tropical rain forests, where most of the nutrient stock remains, and the greater part of the nutrient cycle takes place, *above* the ground. In cool humid climates the cycle is impeded, and valueless plants such as heather constitute the type vegetation. The ideal agricultural soil is one in which the cycle is fairly shared between soil and plant. Artificial modifications in pursuit of the full roundedness of the soil/plant cycle are the purpose of man's operations in cultivation and manuring.—(Abstracted from an article by Dr. Hugh Nicol, in *Nature*, Vol. CL, No. 3792, 1942.)